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Marketable quality and phytonutrient concentrations of a novel hybrid muskmelon intended for the fresh-cut industry and its parental lines: Whole-fruit comparisons at harvest and following long-term storage at 1 or 5 °C

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Abstract

Year-round demand for fresh-cut produce, such as muskmelon (*Cucumis melo* L. Reticulatus group) fruit, can include importation of whole-fruit from as far away as Chile, requiring expensive air shipments. Surface shipments would reduce these transportation expenses but would also require a longer shelf-life fruit than what is now commercially available to withstand the shipping/storage time frame of up to 5 weeks prior to fresh-cut processing. Current muskmelon cultivars have a fruit storage life of up to 2 weeks. In this 2-year study, we compared the marketable quality and phytonutrient attributes of a novel hybrid with its muskmelon parental lines (ultra-firm female × commercial muskmelon cultivar type male) up to 5 weeks at 1 or 5 °C. At harvest whole hybrid fruit were larger (33–37% heavier) than its parental lines, and had an external firmness equal to its female parent. The external and internal firmnesses of the female parent were on average 4.5-fold and 3.6-fold firmer, respectively, than those of the male parent. Compared to its male parent, the internal tissue of hybrid fruit was relatively sweeter, more intensly orange, had a higher concentration of β-carotene, had a seven-fold higher concentration of 5-methyltetrahydrofolate (folic acid), had fewer internal disorders, and reduced senescence. The aforemetioned tissue firmness of hybrid fruit would make it highly suitable to withstand surface shipments of up to 5 weeks; and the aforementioned quality characteristics would make it likely preferable to consumers both taste-wise and nutritionally as a fresh-cut product.
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Keywords: *Cucumis melo*; Ascorbic acid; β-Carotene; Color; Fruit firmness; 5-Methyltetrahydrofolate (folic acid); Malondialdehyde; Sugars; Sweetness

1. Introduction

Fresh-cut fruit has been a rapidly growing segment of the produce industry and is expected to exceed U.S. $1 billion by 2008 (Clement, 2004). Fresh-cut melon products are a significant segment of the fresh-cut fruit industry. Although U.S. consumer demand for whole and fresh-cut melons is year-round, the domestic U.S. melon industry is unable to provide the necessary product volume to fulfill this demand especially during the winter season in the U.S. As a result, melons obtained from local growers or other areas within the U.S. during the summer months are imported from Central America during the winter season. Fruit from U.S. and Central America are harvested at different maturities to accommodate different transit times. Melons from southern hemisphere production areas are generally not imported into the U.S. due to (a) their relatively short shelf-life, (b) the unacceptably long (>2 weeks) surface transit times and (c) the formidable expense of air shipment. Since surface transit times from southern hemisphere production areas to the U.S. take up to 5 weeks, production of a melon fruit with typical muskmelon attributes combined with a relatively long shelf-life is required for overseas surface shipments. Unfortunately no

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such commercial cultivar is available commercially. As a result, many melon breeding efforts in the U.S. actively seek germplasm world-wide that produce fruit that can be stored for 4–5 weeks and that have or can be bred with a flavorful muskmelon cultivar to have fruit with flavor, texture, and color attributes suitable for fresh cutting (Paul Chung, melon breeder, personal communication).

One such melon breeding effort by Seminis Seed Co., CA has produced a novel muskmelon hybrid from a cross between an ultra-firm netted melon genotype (female) and a commercial muskmelon cultivar genotype (male). Hybrid fruit stored 5 weeks at 1 °C under modified atmosphere conditions, then fresh-cut and stored for 14 days in air at 5 °C maintained good quality and was generally preferred by consumers to its inbred parents and to cantaloupes and honeydews available during the winter (Robert Saftner, unpublished data). In this study, we compared commercially grown hybrid fruit with its parental line fruit following two different harvests (years) and three different storage durations (0, 3 and 5 weeks) at two different commercial shipping/storage temperatures (1 and 5 °C) for whole-fruit marketable quality indices and phytonutrient contents. The overall objective of this study was to assay the market quality attributes of a novel, long shelf-life hybrid melon fruit intended for fresh-cut processing, and determine its whole-fruit quality and phytonutrient contents following long-term storage simulating surface transit times from the southern hemisphere to the U.S.

2. Materials and methods

2.1. Plant material and fruit storage conditions

Ultra-firm netted melon genotype female and commercial netted-muskmelon cultivar/genotype male parental line and F1 hybrid fruit were supplied by Seminis Seed Co., Oxnard, CA. Fruit were commercially grown at the Seminis Seed Co. research station in Woodland, CA in 2005 and 2006, harvested at equal ripeness (cut, hybrid and female parental line, and 3/4-slip male parental line) in August, chilled to 4 °C, and shipped in insulated containers overnight to the U.S.D.A. Agricultural Research Service, Kika De la Garza Subtropical Agricultural Research Center, Weslaco, TX. All fruit upon arrival were checked for soundness; fruit free of defects were washed in 3.3% bleach, rinsed in tap water, air-dried and randomized into lots of ten fruit for storage. Each lot of fruit was placed in a commercial muskmelon shipping box lined with a plastic StePak storage bag (StePak Corp., Encinetas, CA) sealed with a twist-tie. A modified atmosphere of >13 kPa oxygen and <8 kPa carbon dioxide was passively established within all bags during storage at 1 °C when sealed with a twist-tie. Fruits were stored at 1 or 5 °C. Chamber relative humilities (RH) were 38 ± 1% and 39 ± 2%, respectively. The RH inside the bags was ~90%.

2.2. Fruit weight loss, firmness, and soluble solids concentration determinations

Whole-fruit fresh weight loss is expressed as the percentage loss of the initial fruit fresh weight. Firmness of the whole-fruit equatorial hypodermal-mesocarp tissue, minus the peel, and the middle-mesocarp tissue from an equatorially cut fruit, was measured and expressed as mean force in Newtons (Lester and Grusak, 2004). Soluble solids concentrations (SSC) were determined on expressed juice of middle-mesocarp sections from three different locations along the fruit equatorial circumference excluding the ground spot (Lester and Grusak, 2004).

2.3. Color determinations

A chromameter (CR-200: Minolta Corp. Ramsey, NJ), calibrated using a clean white ceramic plate (L^* = lightness, C^* = chroma, h° = hue angle), was used to quantify fruit mesocarp tissue color indicies. The surface color of middle-mesocarp tissue at three locations around the cross-section of each fruit cut at the equatorial plane were measured and mean values expressed in the L^*, C^*, and h° mode.

2.4. Internal fruit disorders

Following storage, all fruit were rated for internal disorders that would affect marketability as a fresh-cut product. Ratings were 0 = no detectable disorders; 1 = ≤15% of each fruit with disorders; 2 = 16% to 50% of each fruit with disorders; 3 = 51% to 85% of each fruit with disorders; 4 = >85% of each fruit with disorders. The data were arcsine transformed (Little and Hills, 1978) before analysis of variance to correct for variance heterogenity and presented as percent disorders.

2.5. Fruit processing

Following 0–5 weeks storage, each lot of fruit was separately washed with distilled water, fruit peels were removed with a vegetable peeler, and the blossom and stem ends (totaling two-thirds of the fruit) cut away with a sharp knife and discarded. Wedges of remaining equatorial-region mesocarp (pulp) tissue, devoid of seeds and integument tissue, were pureed in a food processor (Quick 'N Easy; Black and Decker, Towson, MD) using 3–5 s pulses. Pureed tissue samples were assayed fresh for malondialdehyde concentrations; frozen (liquid nitrogen, then stored at −80 °C for <30 days) for ascorbic acid and folic acid analyses; and lyophilized for β-carotene, minerals, and sugar determinations.

2.6. Vitamin assays

Free ascorbic acid and dehydroascorbate were extracted from 7.5 g frozen (−80 °C) tissue puree and reported as total ascorbic acid (Hodges et al., 2001). β-Carotene was extracted under low light conditions from 20 mg samples of lyophilized tissue puree (Lester et al., 2005). Folic acid, as 5-methyltetrahydrofolate, was extracted from 7.5 g samples of frozen tissue puree (Lester and Crosby, 2002).

2.7. Metabolite assays

Malondialdehyde content was determined on 2.0 g samples of freshly pureed mesocarp tissue using the TBARS procedure (Hodges et al., 1999).

2.8. Sugars

Fruit sugars were extracted from 0.3 g samples of lyophilized tissue by homogenizing in 5 mL 80% ethanol at 80 °C using a Polytron (Polytron, Kinematica, GmbH, Luzen, Switzerland) at speed #6 for 5 s, the homogenate was filtered (Whatman No.1; Maidestone, United Kingdom) and the residue washed with 5 mL 80% ethanol at 80 °C. One millilitre of the combined filtrate was reduced to 0.2 mL at 50 °C under N_2, brought back to 1 mL with high-performance liquid chromatography (HPLC) grade water, then passed through a pre-wetted (HPLC water) C18 Sep-Pak (Waters Corp., Milford, MA) filter. Fructose, glucose and sucrose were separated by HPLC and quantified by co-chromatography against known concentrations of each sugar standard with refractive-index detection. The HPLC (1100 Series, Agilent Technologies, Santa Clara, CA) contained a Supelcogel Ca guard column/Supelcogel Ca column (30 cm × 7.8 mm i.d., Supelco, Bellefonte, PA) heated to 80 °C and 0.5 μL samples were eluted with HPLC-grade water at 8.33 μL s^{-1}. Tissue dry weight was determined as a percentage of fresh tissue weight after lyophilization.

2.9. Statistics

Five fruit per genotype/hybrid per storage regime (90 fruit total) were used in both 2005 and 2006 repetitions of this study. Data were subjected to analysis of variance using the general linear model (GLM) procedure of SAS Ver. 9.1 (SAS, Cary, NC). Treatment means were compared using the least square means (LSMEANS) procedure of SAS. Only significant results are discussed unless stated otherwise.

3. Results and discussion

Hybrid fruit were heavier than both parental line fruit and this fresh weight difference was maintained throughout storage (Table 1). Hybrid fruit could consistently yield a greater piece yield of fresh-cut product than that of either parental line fruit. Fruit weight loss was less for hybrid fruit compared to both parental line fruit throughout storage, and weight loss was generally less when stored at 1 °C versus 5 °C. Following 21 days storage, all fruit regardless of temperature had fresh weight losses of >5%. Weight losses of this magnitude are known to result in softened fruit with shriveling around the stem scar that affects marketability (Ryall and Lipton, 1978). Softening (firmness) in *Cucumis melo* fruit is highly linked with fruit moisture loss (Lester and Bruton, 1986) and associated cell membrane leakage (Lester and Stein, 1993) and, to a lesser extent, with cell wall disassociation (McCollum et al., 1989). Both membrane leakage- and cell wall disassociation-influenced fruit softening may be present in this germplasm. Although female parental line fruit demonstrated relatively high fruit moisture loss, i.e., 10.3% when averaged for both years following 5 weeks at 5 °C, the average external fruit firmness declined only 27%. This is in contrast to male parental line fruit, which had the same moisture loss (10.3%) during the same storage period, but demonstrated a 20% greater (average 47%) decline in external fruit firmness. Hybrid fruit had the least moisture loss (average 8%) among lines during storage but had the same external fruit firmness decline (average 42%) as that in the male parental line.

Differences among fruit lines for internal firmness followed the same pattern as those for external firmness. Female line fruit were firmer at harvest and following storage over both years than the male or hybrid line fruit. Hybrid fruit internal firmness declined with storage duration, but the decline was substantially greater when stored at 5 °C versus 1 °C. Differences in weight loss among the fruit lines and associated losses in mesocarp tissue firmness indicate possible, heritable physicochemical differences in cell wall- versus membrane-related fruit softening.

A direct measure of cell wall- versus cell membrane-related fruit softening is mesocarp tissue malodialdehyde (MDA) concentrations (Table 2). Malondialdehyde, a secondary end-product of polyunsaturated fatty acid oxidation, provides a measure of lipid peroxidation (Hodges et al., 1999) and associated cell membrane dissociation resulting in cell leakage and fruit softening (Lester, 2000). Male line fruit had higher MDA concentrations, especially when stored at 5 °C versus 1 °C than female line or hybrid line fruit. Higher MDA concentrations signal greater membrane versus cell wall dissociation, due to oxidative stress, which is reflected in heightened tissue disorders and hastened senescence (Lacan and Baccou, 1998). The percent disorders in male line fruit increased with storage duration and storage temperature, which coincided with increasing MDA concentrations. In contrast, female and hybrid line fruit had lower MDA concentrations throughout storage, i.e., less membrane dissociation, and substantially lower internal disorders, resulting in relatively reduced senescence. Although hybrid fruit had

Table 1
Comparison of commercially grown netted hybrid with parental lines (female = ultra-firm netted melon genotype; male = commercial muskmelon cultivar/genotype) for whole-fruit size (weight), moisture loss (weight loss) and hypodermal (external) and middle-mesocarp (internal) firmness at harvest and following storage in modified atmosphere bags for 3 or 5 weeks at 1 or 5 °C

Fruit line	Storage (weeks)	Temperature (°C)	Fresh weight (kg)		Weight loss (%)		External firmness (N)		Internal firmness (N)	
			Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Female	0	23	1.44 B[a],a[b]	1.30 B,a	nd[c]	nd	86.5 A,a	95.7 A,a	42.1 A,a	56.9 A,a
Male	0	23	1.30 B,a	1.31 B,a	nd	nd	36.4 B,a	14.0 B,a	12.6 C,a	7.2 C,a
Hybrid	0	23	2.07 A,a	2.00 A,a	nd	nd	89.7 A,a	84.7 A,a	31.4 B,a	34.7 B,a
Female	3	1	1.53 B,a	1.24 B,a	6.3 A,c	5.2 A,b	88.9 A,a	91.9 A,a	35.4 A,a	44.9 A,b
Male	3	1	1.43 B,a	1.40 B,a	7.2 A,b	5.1 A,b	29.5 C,b	10.2 B,b	10.8 B,a	7.6 C,a
Hybrid	3	1	2.11 A,a	1.91 A,a	6.0 A,c	4.3 B,b	67.1 B,b	89.3 A,a	17.8 B,b	32.9 B,a
Female	3	5	1.40 B,a	1.32 B,a	6.1 B,c	8.7 A,a	79.0 A,b	90.0 A,a	40.9 A,a	50.8 A,b
Male	3	5	1.66 B,a	1.30 B,a	8.3 A,b	5.9 B,b	27.3 C,b	10.3 C,b	6.1 B,b	6.7 C,a
Hybrid	3	5	2.14 A,a	1.90 A,a	5.7 B,c	5.1 B,b	45.3 B,c	68.9 B,b	11.6 B,b	15.6 B,b
Female	5	1	1.40 B,a	1.25 B,a	8.0 A,b	8.7 A,a	80.1 A,b	72.2 A,b	40.9 A,a	50.8 A,b
Male	5	1	1.53 B,a	1.36 B,a	7.8 A,b	6.7 B,b	22.0 C,b	9.6 B,b	6.7 C,b	6.5 C,a
Hybrid	5	1	2.03 A,a	1.93 A,a	7.3 B,b	5.2 B,b	51.8 B,c	70.6 A,b	17.8 B,b	37.0 B,a
Female	5	5	1.50 B,a	1.33 B,a	10.6 A,a	9.9 A,a	67.5 A,c	66.2 A,b	35.4 A,a	47.8 A,b
Male	5	5	1.61 B,a	1.30 B,a	11.3 A,a	9.2 A,a	15.7 C,c	9.0 C,b	6.0 B,b	5.7 B,a
Hybrid	5	5	2.06 A,a	1.93 A,a	8.7 B,a	7.3 B,a	47.9 B,c	51.9 B,c	10.2 B,b	11.4 B,b

[a] Upper-case letters within a column indicate significant differences (LSMEANS 5% level) among fruit lines within a storage period and temperature.
[b] Lower-case letters within a column indicate significant differences (LSMEANS 5% level) over the storage period within a fruit line.
[c] nd = not determined.

Table 2
Comparison of commercially grown netted hybrid with parental lines (female = ultra-firm netted melon genotype; male = commercial muskmelon cultivar/genotype) for malondialdehyde (MDA) concentration, disorders (percent of tissue affected) and internal (edible) fruit tissue surface color at harvest and following storage in modified atmosphere bags for 3 or 5 weeks at 1 or 5 °C

Fruit line	Storage (weeks)	Temperature (°C)	MDA		Disorders (%)		Lightness[a]		Chroma[b]		Hue angle[c]	
			Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Female	0	23	1.5 A[d],a[e]	1.4 A,a	0	0	62.1 B,b	64.1 B,b	38.9 A,a	38.6 A,a	68.5 A,a	70.2 B,a
Male	0	23	1.3 A,c	1.1 A,c	0	0	67.2 A,b	67.5 A,b	38.1 A,a	32.9 B,a	71.2 A,b	74.8 A,a
Hybrid	0	23	1.4 A,a	1.5 A,b	0	0	63.6 B,a	64.5 B,a	37.2 A,a	38.4 A,a	70.0 A,a	71.5 B,a
Female	3	1	1.2 A,a	1.4 A,a	0	0	62.2 B,b	65.2 B,b	39.6 A,a	40.7 A,a	70.5 A,a	68.7 B,a
Male	3	1	1.5 A,c	1.6 A,bc	1	0	67.1 A,b	68.7 A,b	37.0 A,ab	32.4 C,a	71.8 A,b	74.9 A,a
Hybrid	3	1	1.5 A,a	1.3 A,b	0	0	63.9 B,a	65.2 B,a	35.0 B,ab	37.1 B,a	70.7 A,a	72.5 AB,a
Female	3	5	1.5 B,a	1.4 B,a	0	0	64.6 B,a	68.6 A,a	40.9 A,a	35.6 A,a	69.1 B,a	70.8 B,a
Male	3	5	2.7 A,b	2.6 A,ab	15	10	68.8 A,ab	69.1 A,ab	35.0 B,b	31.1 B,ab	73.7 A,a	74.1 A,a
Hybrid	3	5	1.5 B,a	1.5 B,b	0	0	65.6 B,a	64.6 B,a	35.4 B,ab	36.2 A,a	71.6 AB,a	71.4 B,a
Female	5	1	2.0 AB,a	1.9 B,a	0	0	63.0 A,b	66.4 B,b	40.3 A,a	40.8 A,a	69.3 B,a	70.0 B,a
Male	5	1	2.7 A,b	3.0 A,a	1	15	67.9 A,b	68.4 A,b	34.3 B,b	31.4 C,ab	74.6 A,a	75.3 A,a
Hybrid	5	1	1.5 B,a	2.0 B,ab	0	1	63.4 A,a	64.9 B,a	35.8 B,ab	36.9 B,a	72.5 A,a	72.2 B,a
Female	5	5	2.4 B,a	1.4 C,a	1	1	65.6 B,a	68.2 A,a	38.6 A,a	38.7 A,a	70.5 A,a	71.6 B,a
Male	5	5	4.2 A,a	3.8 A,a	22	21	69.1 A,a	70.1 A,a	34.7 B,b	30.1 C,ab	73.7 A,a	75.2 A,a
Hybrid	5	5	2.4 B,a	2.9 B,a	2	10	64.5 B,a	65.2 B,a	33.2 B,b	33.8 B,b	70.8 A,a	72.0 B,a

[a] Lightness (+100 = white, −100 = black).
[b] Chroma = color intensity.
[c] Hue angle (0° = red, 90° = yellow, 180° = green, 270° = blue).
[d] Upper-case letters within a column indicate significant differences (LSMEANS 5% level) among fruit lines within a storage period and temperature.
[e] Lower-case letters within a column indicate significant differences (LSMEANS 5% level) over the storage period within a fruit line.

few disorders and reduced senescence (less MDA) it is unknown whether the firmer tissue of hybrid versus the commercial male line fruit is a suitable market place quality attribute.

An important marketable (consumer acceptance) quality attributes is melon flesh color (Francis, 1980). Melon flesh color is a measure of lightness (black = −100 and white = +100), chromaticity or chroma (color intensity) and hue (color purity) (Table 2). The typical orange-fleshed muskmelon hue (h°) lies between 0° (red) and 90° (yellow). The mesocarp tissue of the female line and hybrid fruit had a lower h°, more red than yel-

Table 3
Comparison of commercially grown netted hybrid melon with parental lines (female = ultra-firm netted melon genotype; male = commercial muskmelon cultivar/genotype) for internal (edible) fruit soluble solids concentration, total sugars and relative sweetness rating on a fresh weight basis and percent dry weight at harvest and following storage in modified atmosphere bags for 3 or 5 weeks at 1 or 5 °C

Fruit line	Storage (weeks)	Temperature (°C)	Soluble solids concentration (%)		Total sugars (g/kg)		Relative sweetness (g/kg sucrose equivalents)[a]		Dry weight (%)	
			Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Female	0	23	11.0 A[b],a[c]	11.8 A,a	103 A,a	94 A,a	115 A,a	103 A,a	12.4 A,a	13.6 A,a
Male	0	23	9.5 A,a	8.4 B,a	93 A,a	75 B,a	85 B,b	87 B,a	9.8 B,a	8.9 B,a
Hybrid	0	23	12.0 A,a	12.7 A,a	101 A,a	93 A,c	116 A,a	102 A,c	12.0 A,a	12.5 A,a
Female	3	1	11.8 A,a	11.3 A,a	98 AB,ab	88 B,a	111 AB,a	99 B,ab	12.4 A,a	11.2 A,b
Male	3	1	10.7 A,a	8.9 B,a	91 B,ab	74 C,a	105 B,a	85 C,a	10.0 A,a	9.9 A,a
Hybrid	3	1	12.2 A,a	11.7 A,a	105 A,a	146 A,a	119 A,a	165 A,a	12.1 A,a	11.5 A,a
Female	3	5	10.4 A,a	9.4 B,b	90 A,b	71 B,b	106 A,a	85 B,bc	11.4 A,a	9.4 B,b
Male	3	5	10.0 A,a	9.1 B,a	81 A,b	77 B,a	94 B,b	92 B,a	10.2 A,a	9.3 B,a
Hybrid	3	5	11.0 A,a	11.7 A,a	91 A,a	111 A,b	105 A,b	125 A,b	11.9 A,a	11.7 A,a
Female	5	1	11.3 A,a	10.8 A,a	97 A,ab	90 A,a	113 A,a	100 A,a	11.8 A,a	11.1 A,b
Male	5	1	9.9 A,a	9.0 A,a	86 B,ab	71 B,a	112 A,a	80 B,a	10.2 A,a	9.9 B,a
Hybrid	5	1	11.5 A,a	11.0 A,a	96 AB,a	93 A,c	113 A,ab	105 A,c	12.0 A,a	11.1 A,a
Female	5	5	10.0 A,a	9.0 A,b	79 B,c	68 B,b	91 B,b	81 B,bc	10.8 A,a	9.4 A,b
Male	5	5	9.7 A,a	8.7 A,a	81 B,b	50 C,b	94 B,b	61 C,b	8.6 B,a	8.6 A,a
Hybrid	5	5	11.1 A,a	10.0 A,a	93 A,a	86 A,c	111 A,ab	98 A,c	11.4 A,a	11.1 A,a

[a] Relative sweetness rating = 1.8 (g/kg fructose) + 0.7 (g/kg glucose) + 1.0 (g/kg sucrose).
[b] Upper-case letters within a column indicate significant differences (LSMEANS 5% level) among fruit lines within a storage period and temperature.
[c] Lower-case letters within a column indicate significant differences (LSMEANS 5% level) over the storage period within a fruit line.

low hue, i.e., more orange-colored than male line fruit. The orange hue was more saturated in female fruit than hybrid fruit, especially in 2006. Fruit from the male parent had a more yellowish-orange. Lightness was generally lower in the female and hybrid fruit than in male mesocarp tissue and remained so throughout storage. The mesocarp tissue of male line fruit had the highest L^* at harvest and throughout storage at both harvests, giving the tissue a slightly whitish (bleached) appearance. Surveys have shown consumers prefer melon fruit pieces that have a clear, intense typical melon orange hue (Francis, 1980); thus hybrid (and female) fruit pieces, according to our data, should be highly acceptable in appearance to consumers.

The overall consumer acceptance of melons is highly correlated with taste ($r = 0.98$) and taste is highly correlated with sweetness or fruit sugar content ($r = 0.99$) (Lester and Shellie, 1992). Sugars in melon fruits are determined either directly as individual carbohydrates or indirectly as SSC. Purees of hybrid fruit mesocarp tissue had the highest SSC both years and generally maintained higher concentrations throughout storage though the differences were not always significant (Table 3). Total sugar content and relative sweetness ratings [a calculated rating (Table 3) reflecting human taste] corroborated SSC findings, with hybrid fruit always, and usually significantly, having the highest total sugars and relative sweetness following harvest and throughout storage (Table 3). Percent dry weight, which measures solids content, corroborates the higher SSC and total sugar contents found in hybrid versus male line fruit.

In addition to the superior consumer preference traits (appearance and sweetness) hybrid fruit were a rich source, generally, albeit not always significantly, better than the male parent, in ascorbic acid, β-carotene and folic acid (Table 4). Human intake of ascorbic acid, β-carotene (pro-vitamin A), folic acid, and α-tocopherol (not found in melon fruit) are the four major vitamins essential for human health. They are considered to be critically low in American diets by the U.S. Government and should be obtained from eating a variety of fruits and vegetables rather than from vitamin supplements (USDA, 2005). Antioxidant vitamin supplements recently have been linked to increased mortality (Bjelakovic et al., 2007).

In our study, male line fruit, at harvest (0-day storage), represented the USDA Standard Reference for muskmelon fruit ascorbic acid concentration (USDA, 2004). The female parent and hybrid fruit had about 30% more ascorbic acid than male parent fruit at harvest for both years and maintained higher concentrations when stored at 1 °C. However, the ascorbic acid concentrations decreased by as much as 62% after 5 weeks storage at 5 °C and the initial differences among melon genotypes was lost during storage at the higher temperature.

The USDA Standard Reference for muskmelon fruit β-carotene is 20 mg kg^{-1} (USDA, 2004). Hybrid fruit, if averaged for both harvests, equaled that concentration; whereas female fruit were 40% higher and the male line fruit were 20% lower (Table 4). When averaged over both harvests for each genotype, β-carotene concentrations declined only in female fruit stored at 5 °C.

Folic acid is notably high in fruit at harvest regardless of year or genotype (Table 4). Folic acid concentration in commercial muskmelon fruit is ~250 μg kg^{-1} (USDA, 2004). Male parent fruit concentrations were up to 1.5-fold higher than the USDA Standard Reference but female line and hybrid fruit were a surprising seven- to eight-fold higher. Folic acid declined in all fruit with storage time, with the rate of decline greater in female line versus male line or hybrid fruit; and with correspondingly greater declines occurring at 5 °C than at 1 °C. Even though folic acid in hybrid fruit declined 15% and 42% during 5 weeks storage at

Table 4
Comparison of commercially grown netted hybrid melon with parental lines (female = ultra-firm netted melon genotype; male = commercial muskmelon cultivar/genotype) for internal (edible) fruit total ascorbic acid, β-carotene, and 5-methyltetrahydrofolate (folic acid) at harvest and following storage on a fresh weight (FW) basis in modified atmosphere bags for 3 or 5 weeks at 1 or 5 °C

Fruit line	Storage (weeks)	Temperature (°C)	Ascorbic acid (mg/kg)		β-Carotene (mg/kg)		Folic acid (μg/kg)	
			Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Female	0	23	453 A[a],a[b]	494 A,a	27 A,a	31 A,a	1599 A,a	1739 A,a
Male	0	23	347 B,a	271 B,ab	16 B,a	16 C,a	491 B,a	468 B,ab
Hybrid	0	23	447 A,a	453 A,a	19 B,a	26 B,a	1346 A,a	1522 A,a
Female	3	1	411 A,a	438 A,a	22 A,ab	32 A,a	1219 A,b	1298 A,b
Male	3	1	313 A,a	295 B,a	16 B,a	16 C,a	420 B,a	469 B,a
Hybrid	3	1	437 A,a	439 A,a	21 AB,a	21 B,a	1276 A,a	1080 A,b
Female	3	5	263 A,b	205 A,b	21 A,b	21 AB,b	1008 A,c	784 A,c
Male	3	5	244 AB,b	174 A,b	14 B,a	19 B,a	308 B,b	373 B,b
Hybrid	3	5	153 B,b	223 A,b	18 AB,a	25 A,a	757 A,b	864 A,c
Female	5	1	408 A,a	456 A,a	22 A,ab	33 A,a	1368 A,b	1313 A,b
Male	5	1	241 B,b	248 B,ab	12 B,a	14 C,a	412 B,a	342 B,b
Hybrid	5	1	353 A,a	407 A,a	17 A,a	23 B,a	1307 A,a	1121 A,b
Female	5	5	249 A,b	234 A,b	23 A,ab	25 A,b	1022 A,c	758 AB,c
Male	5	5	141 A,b	167 A,b	12 B,a	14 B,a	273 B,c	289 B,b
Hybrid	5	5	185 A,b	157 A,b	16 B,a	21 A,a	806 A,b	834 A,c

[a] Upper-case letters within a column indicate significant differences (LSMEANS 5% level) among fruit lines within a storage period and temperature.
[b] Lower-case letters within a column indicate significant differences (LSMEANS 5% level) over the storage period within a fruit line and storage temperature.

1 °C and 5 °C, respectively, concentrations were still greater than three-fold higher than the USDA Standard Reference following storage.

In conclusion, melon fruit with typical muskmelon quality attributes combined with a relatively long shelf-life (up to 5 weeks) is required for overseas surface shipments to supply the fresh-cut industry during lags in U.S. production. Currently it appears that one such melon hybrid exists. The Seminis Seed Co. hybrid, a cross between an ultra-firm netted melon genotype and a commercial muskmelon cultivar genotype, has relatively low moisture loss, decay-related disorders and senescence (MDA) attributes making it suitable for long-term surface shipment. It also has potentially superior piece yield (fruit size), a quality-related orange hue, firmness and sweetness attributes and health-related bioactive compound contents making it likely highly suitable for fresh-cut processing and marketing.

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